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Modification of a Commutator Motor and its Operation As a Repulsion Motor

Electrical Engineering

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MODIFICATION OF A COMMUTATOR MOTOR AND ITS OPERATION AS A REPULSION MOTOR

BY

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CHARLES ANSON NASH

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE

IN ELECTRICAL ENGINEERING

IN THE

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DONALD ALISON HENRY and CHARLES ANSON NASH

ENTITLED MODIFICATION OF A COMMUTATOR MOTOR AND ITS OPERATION AS A REPULSION MOTOR

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

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INDEX.

	Page
Introduction- - - - - - - - - - - - - - - - - - - -	1
Description of Motor and Brush Shifter - - - - - -	3
Method of Test and Data Taken - - - - - - - - - - -	6
1. Variation of transformer action	7
2. Combined generator and transformer action	9
3. Static torque test	9
4. Speed variation with brush shift	9
5. Speed variation with impressed voltage	10
6. Speed variation with width of brushes	11
7. Effect of resistance and reactance in armature circuit	11
Theoretical Discussion of Data - - - - - - - - - -	14
Discussion of Data and Conclusions - - - - - - - -	24
Data -	29
Variation of transformer voltage	29
Variation of counter E.M.F.	30
Variation of E", E , and E	31
Variation of speed with voltage	32
Variation of static torque	36
Variation of speed with brush shift	37
Effect of reactance on the speed curve	38
Curves -	42
List of References - - - - - - - - - - - - - - - -	49

INTRODUCTION.

Every motor combines the characteristics of a motor and of a generator. The generator characteristics are due to the counter electro-motive force generated in the armature of the motor, this counter electro-motive force being proportional to the speed and to the field flux. An induction motor, when the rotor is held stationary, acts the same as a short-circuited transformer. A repulsion motor differs from an induction motor primarily, in that, instead of having each coil on the armature short-circuited separately and all of the time, any one coil is only short-circuited separately when a brush connects the two commutator segments to which that coil is connected, and, that the armature of a four pole machine is divided into four parts, each of which is short-circuited, the current passing through the coils in series in each part.

The relation between the internal motor, generator and transformer actions in a repulsion motor, depends upon the point of commutation and therefore upon the position

of the brushes. It is the object of this investigation to study, by means of a specially constructed brush shifting mechanism, the change in the internal actions of the motor as the position of the brushes is changed.

DESCRIPTION OF MOTOR AND BRUSH SHIFTER.

The motor used in this investigation was a four pole, ten horse-power, compensated single phase series motor built by the Westinghouse Electric & Manufacturing Company. A photograph of this machine will be found on page four. The motor was built for twenty-five cycle alternating current, and was intended for use as a crane motor. Since, in this service the motor must necessarily run in either direction, the brush holders were rigidly attached to the casing of the machine. There being but very little space between the commutator and the points on the frame to which the brush holders were attached, it was necessaryto bore out the end of the casing to make room for the shifting of the brushes. A ring was turned up to fit the ins-ide of the casing and rigidly attached to it. Another ring carrying the brushes was fitted to the stationary ring in such a manner that it could be easily revolved. By means of a crank and a pinion engaging with teeth cut on the outer edge of the movable ring the brushes were shifted to any desired position.

This being a four pole motor, and the windings being attached to the commutator segments forty-five mechanical degrees from their position in the armature slots, it was necessary to provide means for determining the position of the brushes with respect to the actual coils being commutated. In order to do this a line was established through the centers of two diametrically opposite poles. At a point on this line where it cut the stationary ring a reference point was marked. The movable ring was laid off in electrical degrees, ten degrees to a division, on each side of the zero position, which was also marked on the movable ring. The zero position was so located that when it coincided with the reference point on the stationary ring, the brushes short-circuited the coils which at that instant completely surrounded the poles . Alternate brushes were connected together and two leads were brought out as with the ordinary armature connection of any machine. These two leads were then connected together outside the machine thus short-circuiting the armature. These details are shown in the drawing of the brush shifter on the following page, and the photograph on page four. The drawing is to scale.

METHOD OF TEST AND DATA TAKEN.

During the tests made on this motor the compensating winding was not used, it being simpler to leave it out of consideration. As the motor was not loaded it was not necessary to the good working of the machine.

The motor was supplied with twenty-seven cycle current from a motor-generator set. The generator field was separately excited, and the excitation varied by a number of rheostats in the field circuit. To furthur aid in the adjustment of the impressed voltage, a large one-ohm rheostat was connected in series with the motor circuit.

The tests made were as follows;-

1. Variation of the transformer action with position of brushes.
2. Variation of combined generator and transformer action with brush shift.
3. Variation of static torque with brush position at constant impressed E. M. F.
4. Speed variation, running light, with brush shift and constant E. M. F.

5. Speed variation with voltage, constant brush position.

6. Variation of speed with the width of brushes, constant E. M. F.

7. Effect of resistence and reactance in the armature circuit on the speed characteristics of the motor.

(A load test was tried but the motor would not carry a load large enough to justify the completion of a test.)

1. Variation of Transformer Action.

This test was made with the armature blocked during a greater part of the readings. A constant field current was maintained on the machine, and readings of impressed voltage, field current and power input, taken on the field, and of open-circuit voltage on the armature, for each position of the brushes, while they were shifted through 180° electrical, that is, 90° each side of the zero position, by steps of 10°.

Because of the heavy currents induced in the coils surrounding the poles near the zero position, it was necessary to keep the armature moving slowly to avoid burning out the resistance leads by which the coils on the armature are connected to the commutator bars.

Combined Generator and Transformer Action.

During this test the motor was driven at synchronous speed (810 R. P. M. for 27 cycle current) by a direct current motor. A constant exciting current of 34 amperes was maintained on the field of the motor under test, and the open circuit armature voltage, watts input and impressed voltage were read for different positions of the brushes through a range of 90° on each side of the zero position.

Static Torque Test.

A static torque test was made by means of a prony brake and platform scales. A constant E. M. F. was maintained at the field terminals, and readings of field current, power input, and scale pull were taken for each position of the brushes. Starting with a positive direction of torque at +90° position of the brushes, the torque became negative at -10° position and again reversed at -90° to positive direction.

Speed Variation with Brush Shift.

Having made several preliminary trials, and finding that at certain positions of the brushes, and with a high voltage, the short-circuited current, as well as the line

current, was excessive, the motor was finally started on the 45° position of the brushes with 34 amperes flowing through the field windings and with an impressed voltage of 39 volts. Starting with this condition, the E. M. F. was kept constant and readings of revolutions-per-minute, power input and current were taken for all brush positions between +90° and -90°. The brushes in this case were shifted by 5° increments as the variation in speed was considerable for certain small changes of the brushes.

Speed Variation with Impressed Voltage.

During this test sets of data were taken with the brushes set on the 15°, 30°, 45°, 60°, and 75°, positions, the zero and 90° points giving no rotation. In each brush position the voltage was varied from zero to as large a value as the resulting field current and the sparking would permit.

As the angle of brush shift increased the maximum safe voltage that could be impressed decreased but the maximum speed was reached at the larger angles of shift.

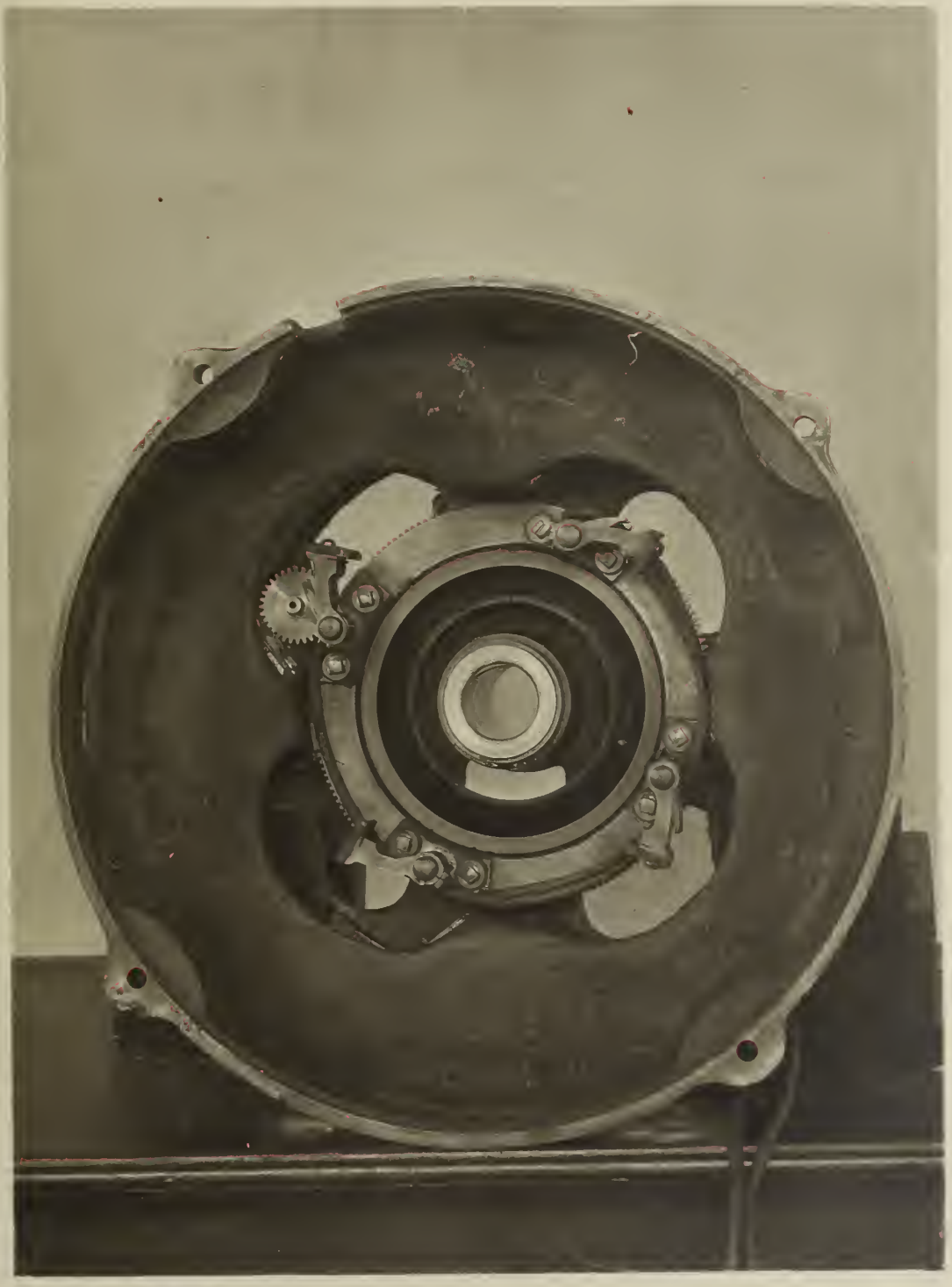
Speed Variation with Width of Brushes.

The brushes which came with the machine were one-fourth inch wide and covered only two commutator bars. In this machine two effects are combined, that of the short circuited armature, and that of the short-circuited coils under commutation. In order to find what relation these actions have to each other, different widths of brushes were tried. This of course had no effect on the short-circuited armature, but did affect the number of short-circuited coils. The brushes tried were 1, 1/4, 1/8 inch wide. The widest brush short-circuited seven coils at one time while the narrow one simply diminished the duration of the short-circuit. Data was taken for a curve of speed and brush position for each width of brushes.

Effect of Resistance and Reactance in the Armature Circuit.

The normal speed curve showed two humps and, in order to give an explanation of the small one, the effect of putting resistance and reactance in the armature circuit was tried. This was also tried for various widths of brushes. The resistance used was a one-ohm rheostat. The reactance was a coil having about 9 ohms reactance.

The speed was taken for increments of 10° of brush shift. There did not appear to be any very marked effect on the speed of the motor due to the added impedance in the circuit.



THEORETICAL DISCUSSION OF DATA.

From a study of the characteristics of this machine it will be seen that it combines the properties of a generator and of a transformer. The generator action is present only while the motor is running, being dependent on the speed, but the transformer action is present at all speeds and varies only with the frequency of the exciting current.

Reffering to the diagram Fig. 1, assume a flux Φ due to the alternating field, which is an alternating flux and evenly distributed over the pole face. Now if a coil "A" on the armature be in such a position that it encloses all this flux it will have induced in it an electro-motive-force E" proportional at each instant to the rate of change of Φ so that it will

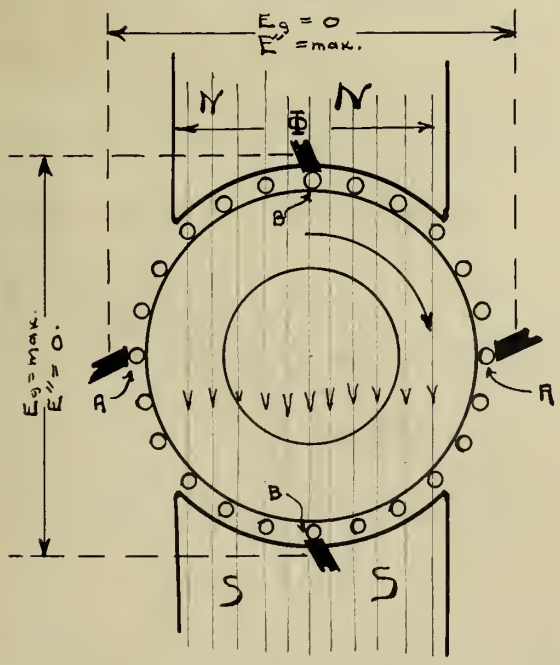


Fig. 1.

lag 90° behind Φ in phase and have a maximum value proportional to that of Φ as shown in Fig. 3. This is the E. M. F. produced by transformer action of the machine.

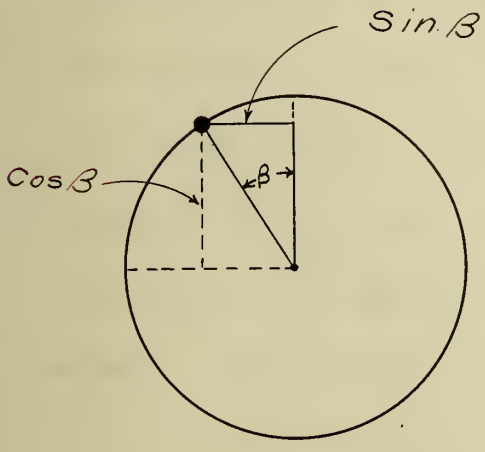


Fig. 2.

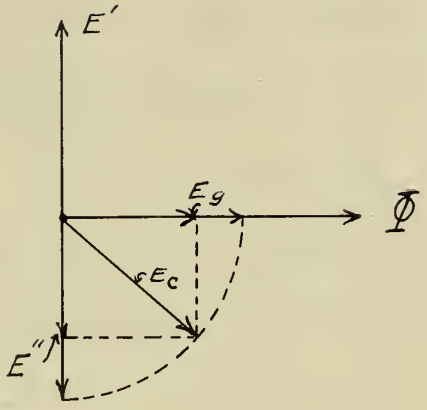


Fig. 3.

If now the brushes are shifted so as to rest on the terminals of another coil which does not enclose the whole flux Φ, the E. M. F. E" induced between brushes will be less and will be proportional to the ammount of flux enclosed by the coil. If the brushes be moved to a coil "B" which is in line with the flux, the flux enclosed will be zero and the voltage induced zero. Now it will be seen from Fig. 2, that the ammount of flux enclosed by any coil will be proportional to the sine of the angle between the vertical and the plane of the coil, therefore we may write the equation;

$$E'' = k \sin\beta$$

where β represents the angle spoken of above. This is the equation representing the transformer E. M. F.

When the machine is in motion it posseses all the characteristics of a generator, that is the armature coils have induced in them an E. M. F. due to their cutting of the field flux Φ. As in the generator this E. M. F. is proportional to the flux and to the rate of cutting. Therefore it is in phase with the flux and dependant on the speed. This is E_g in the diagram Fig. 3. Now this E. M. F. is a maximum in the coil which is cutting the flux at the greatest rate or the coil under the center of the pole and in a vertical position, and it gradually falls off in value in the coils which are cutting at a less rate and becomes zero in the horizontal coil which is cutting no flux. The rate of cutting of flux for a constant angular velocity of the armature varies with the cosine of the angle which the plane of the coil makes with the vertical. We may therefore write for the equation representing the value of this generated E. M.F. ;

$$E_g = k'n \cos\beta$$

where n is the speed of the machine in revolutions per second.

With the motor excited with alternating current it

is however impossible to separate the values of E" and E_g as has been done above. The E. M. F. E" is present at all speeds from zero up, and its value is not affected by the speed. With the motor running therefore the voltage measured between brushes on the armature is a combination of E" and E_g at right angles, or is their vector sum. This value represents the counter electro-motive-force of the motor or E_c on the diagram.

Hitherto we have been considering the action of a two pole motor with an open circuited armature as in arc machines, that is the two ends of a coil are brought to commutator segments 180° apart on the commutator, and to which no other conductors are attached. Certain minor changes are necessary in the argument to make it apply to the commercial machine.

In the ordinary machine such as was used, the effect described above is combined with another effect. In the commercial machine, lap wound, the ends of the separate coils are brought to adjacent commutator segments and all the coils on the armature are connected in a continuous series In this case then the voltage induced in a single coil would be measured between adjacent commutator bars instead of between bars 180° apart. When the brush rests on two

segments, then it short-circuits the coil connected between them. If it is wide enough to rest on three segments it short-circuits two coils and so on. In a four pole machine such as was used in this test, there are four brushes set 90° apart and alternate brushes are connected together. These divide the armature into four parts so that one-fourth of the total number of armature coils are in series between any pair of adjacent brushes. A view of the developed winding of a four pole motor is shown in Fig.4.

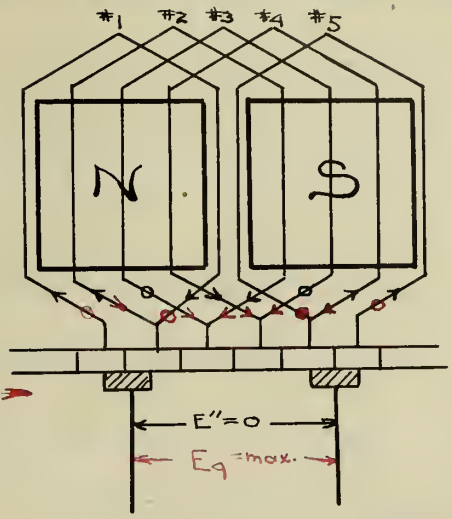


Fig. 4.

It will be seen from this, that coil number 1, which is in a position surrounding the pole and the whole flux, is short-circuited by the brush so that a large current will flow in it. This current will produce a torque, but no voltage will be measurable in the coil. The current will flow in the direction indicated by the black arrows. In

coil no. 2 however the part of the flux from the north pole is tending to produce current in one direction, and that from the south pole tends to send current in the opposite direction. Since the N flux is the largest the current will be as shown. In coil no.3 which is in the centers of N and S the N flux equals the S flux and the resultant voltage will be zero. In coil no.4 the S flux is greater than the N flux so the direction of current will be opposite to that of no.2. The sum of all these E. M. F.s will, therefore, be zero since for each coil under an N pole there is a coil in the same series correspondingly placed under an S pole. The current which would flow in a wire joining the two brushes would then be zero. Therefore this is the position where E" the transformer E. M. F. measured between brushes, is zero.

On the other hand, if we consider the generator E. M. F's. (shown in red on the diagram) we find a different condition. Coil no.1 is cutting no flux and consequently has no E. M. F. generated in it. Coil no.2 is cutting flux from both N and S and the E. M. F. is in the direction shown. Coil no.3 is also under conditions similar to coil no.2 so its E. M. F. is added to that of no.2. Coil no.4 is also added to 2 and 3. Coil no.5

cuts on flux and has no E. M. F. generated in it. This position of the brushes then gives the maximum generator action, in fact, it is the normal position for the brushes of a D. C. generator.

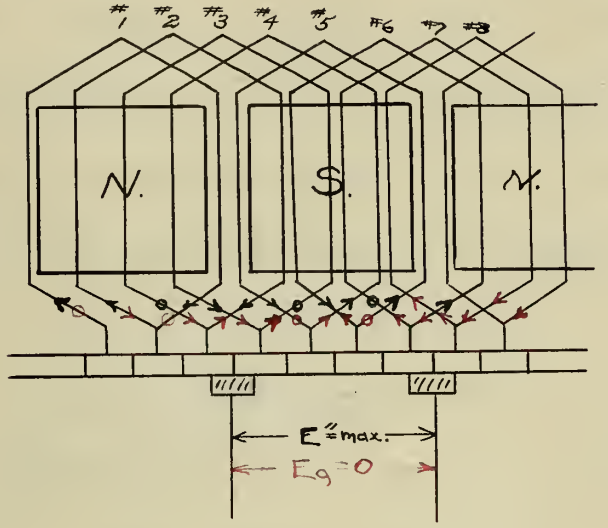


Fig. 5.

Going now to Fig.5 we have shown the state of affairs with the brushes shifted 90 electrical degrees from the position in diagram no. 4. In this diagram the conditions are, therefore, just reversed from those of no.4. That is the sum of the E. M. F's. in coils due to transformer action is a maximum, and the sum of the E.M.F's. generated by rotation is zero. These conclusions are shown by a study of the flux action the same as above. In this case , however, the coil which is short-circuited by the brush encloses as much N flux as it does S flux so that the transformer E. M. F. induced in it is zero and

no current will flow in it on account of this E.M.F. The torque produced by this large short-circuit current in the other case will then be lacking in this position.

To sum up then;

With the brushes on a point shown in Fig.4, which is marked zero degrees, we have the maximum generator action and zero transformer action for the short-circuited armature, with zero generator action and maximum transformer action in the coil under the brush. As the brushes are shifted from this position E_g decreases and E" increases according to the equations before derived, until at a point midway between the poles (marked 90°) E_g has become zero and E" is a maximum.

With the brushes in a position half way between the maximum generator and transformer positions, or where $\beta = 45°$ it is obvious that a speed may be found for which the value of E" is equal to the value of E_g . At this speed we have;

$$E_g = E". \quad (1) \qquad \text{Substituting for } E" \text{ \& } E_g$$

$$k'n \cos\beta = k \sin\beta. \quad (2) \qquad \text{For } \beta = 45°$$

$$\sin\beta = \cos\beta. \quad (3) \qquad \text{Dividing (2) by (3)}$$

$$k'n = k = C. \quad (4)$$

Also we know;

$$E_c = \sqrt{E_g^2 + E''^2} \quad (5) \quad \text{Subst. from (4)}$$

$$= \sqrt{C^2 \sin^2\beta + C^2 \cos^2\beta} \quad (6)$$

$$= \sqrt{C^2(\sin^2\beta + \cos^2\beta)} \quad (7) \quad \text{also}$$

$$\sin^2\beta + \cos^2\beta = 1 \quad (8) \quad \text{or}$$

$$E_c = \sqrt{C^2} \quad (9)$$

$$E_c = C.$$

that is for this speed we have E_c is constant for any value of β.

It now remains to be seen what this speed is. From the equation for transformer induction we have;

$$E'' = \frac{\sqrt{2}\,\pi\, f\, \Phi\, N}{10^8} \quad (1)$$

where f is the frequency in cycles per second, Φ is the maximum value of flux, and N is the number of turns. For generated E.M.F. due to rotation we have this equation;

$$E = \frac{\sqrt{2}\,\pi\, n\, N'\, \Phi}{10^8} \quad (2)$$

where n is the speed in R.P.S. and N' is the actual number of conductors on the armature which cut the flux Φ. We may now equate these two and solve for n which will be the speed at which $E_g = E''$.

$$\frac{\sqrt{2}\,\pi\, f\, \Phi\, N}{10^8} = \frac{\sqrt{2}\,\pi\, n\, \Phi\, N'}{10^8} \quad (3)$$

$$fN = nN' \qquad (4)$$

Now in the armature of a machine the number of turns is just half the number of conductors or;

$$2N = nN' \qquad (5)$$

Substituting this in (4) we have ;

$$f \cancel{N} = 2\, n \cancel{N}$$

$$f = 2\, n$$

$$n = \frac{f}{2}$$

If we have a circuit of frequency of 27 cycles as in this case we find;

$$n = 13.5 \text{ R.P.S.}$$

or the proper speed to make $E'' = E_g$ is 810 R.P.M. This is "synchronous speed" for a four pole motor, running on 27 cycle currents, as stated elsewhere.

DISCUSSION OF DATA AND CONCLUSIONS.

The variation of transformer, generator and counter E. M. F., torque and speed, with brush shift and the variation of speed with voltage, are well shown by the curves plotted from the data taken during the various tests.

Although the motor was driven at synchronous speed, which was stated above as the conditions under which the counter E. M. F. is constant, the value of E_c shows a slight variation. This is probably due in part to a small variation in the impressed E. M. F., and partly to a probable unequal distribution of the flux over the pole face. This is obvious from the fact that the curve seems to be symmetrical with respect to the position of the brushes corresponding to the center of the pole. Inasmuch as the curve plotted from observed values of E" showed very little deviation from the true sine curve, the formulae stated before were assumed to be true, and the values of E_g calculated from the equation;

$$E_g = \sqrt{E_c^2 - E''^2}$$

The curve showing values of E_g, E", and E_c are on page 42.

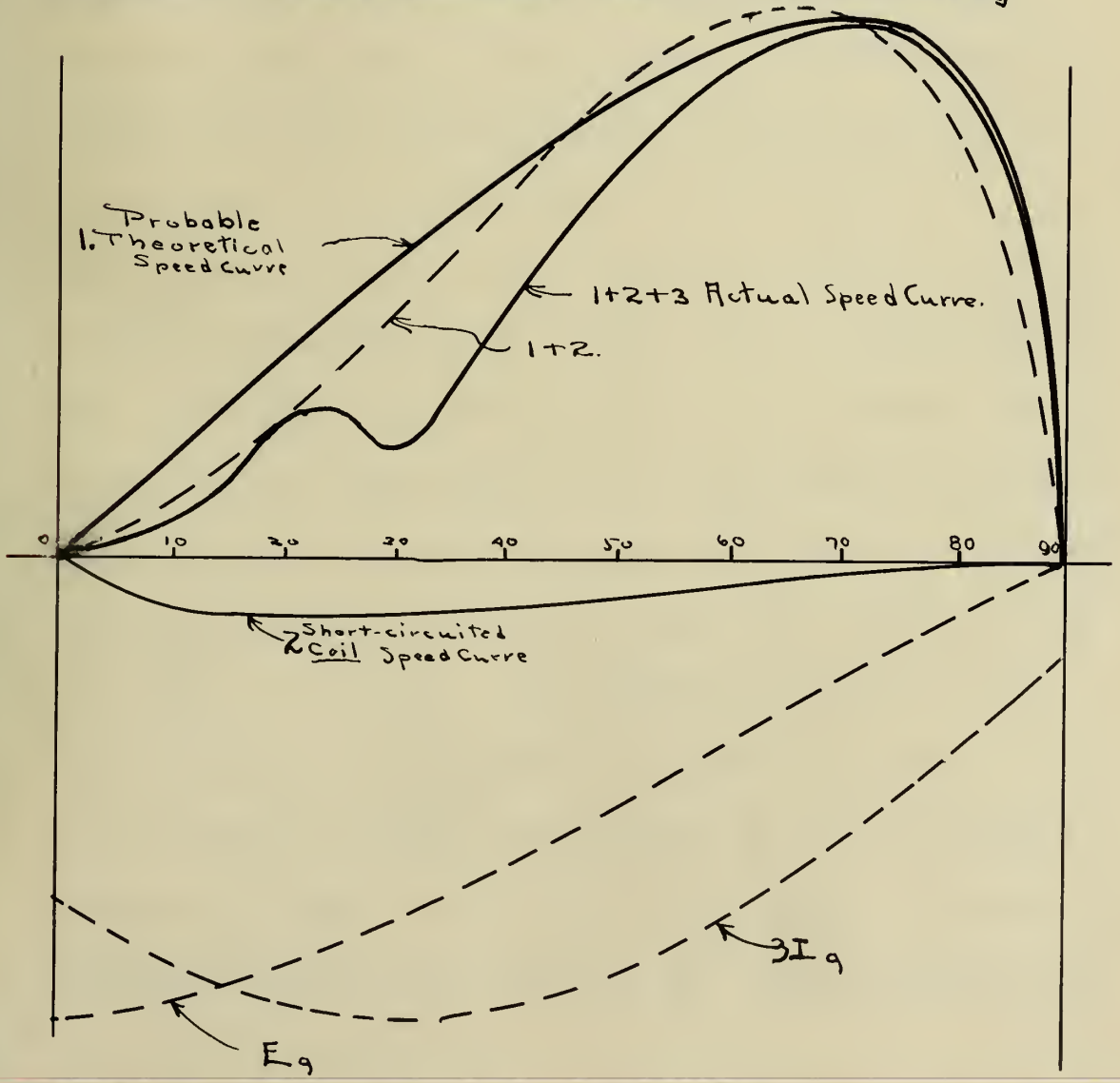
This, of course, gives the curve E_g the same variation from the cosine curve that E" has from the sine curve.

The torque curve shows a great similarity to the curve between torque and slip of an induction motor. This curve was plotted from data taken through a range of values from +90° to -90° of brush shift and shows a smooth curve straight through, with a maximum at about 70°.

Some commercial repulsion motors are built which depend for their action upon the separate short-circuiting of a number of coils on the armature by a very wide brush. The effect of this secondary action of the torque produced by the short-circuiting of coils by the brushes, was investigated by operating the motor with different widths of brushes. The effect on the curves of speed is shown on page 46. It is seen that the form of the curves is entirely different. Although the torque produced by this current was not sufficient to overcome the friction of the machine with the narrow brushes, with the one inch brushes it was found that the motor would run with the armature circuit opened, though it did not attain a very great speed. The rotation under this condition was in the opposite direction to that with short-circuited armature showing that this torque opposes the normal operation of

the machine. The maximum speed with the armature circuit open was reached at about 20°.

The speed curve shows a peculiar form in that it possesses two maximum points, one in the region of 15° and the other at about 80° . The curve for static torque does not show this characteristic. We must conclude, therefore, that the first maximum point is due to some effect of rotation. Now the only thing which is affected by rotation is the generator electro-motive force E_g.



The probable theoretical speed curve with infinitely thin brushes is a smooth curve with a maximum at about 70° as shown. The curve of speed corresponding to the torque produced by the current in the coil short-circuited by the brush is shown. It will be a curve of the same form as the total speed curve, except that it will be opposed to it and have its maximum at about 20°. It is of course, impossible to eliminate the effect of the coil short-circuited by the brush, but its effect may be diminished by diminishing the width of the brushes. This is shown by the fact that the curve for narrow brushes, page 46, rises higher than either of the others at about 10° to 15°. The combination of these two curves would give a curve such as shown by the theoretical speed curve in the diagram 1+2. This curve should be exactly similar to the torque curve. At the smaller brush angles we find the maximum generator action. This decreases the speed that might be obtained because the generator voltage is produced directly at the expense of the torque. The transformer action also is small here which still furthur decreases the speed. As the brushes are shifted the generator E. M. F. decreases allowing the curve to rise higher and higher. With the armature circuit opened the E. M. F. E_g is in phase with

the flux producing it, which is in phase-quadrature with E' the impressed E. M. F. This gives the curve marked E_g in the diagram. When the armature circuit is closed a current will flow due to this E_g ; but on account of the inductivity of the armature circuit, it will lag behind the E.M.F. producing it, giving some such curve as I_g shown. The torque produced by this current will be in phase with I_g and will subtract from the total available torque giving a speed curve corresponding to the actual curve of the form shown in the figure. For this reason the speed curve will have the form found.

VARIATION OF TRANSFORMER VOLTAGE IN ARMATURE.
WITH POSITION OF BRUSHES.
Constant Excitation.(34 Amp.) Armature Stationary.

E" Volts	E' Volts	Power Kilo-Watts	Pos.of Brush Elec.Deg.
89.0	100.0	0.286	+90
86.0	100.0	0.286	80
81.8	100.0	0.286	70
75.0	98.0	0.286	60
65.0	98.0	0.316	50
53.0	98.0	0.386	40
42.0	98.0	0.486	30
27.8	95.0	0.686	20
12.5	95.0	0.786	10
1.0	95.0	0.686	0
17.5	95.0	0.586	-10
32.0	95.0	0.686	20
46.5	95.0	0.636	30
60.5	95.0	0.436	40
69.0	95.0	0.386	50
74.0	90.0	0.336	60
81.0	90.0	0.306	70
84.5	92.0	0.286	80
86.0	93.0	0.286	90

VARIATION OF COUNTER E.M.F.(E_c) WITH POSITION OF BRUSHES.

Synchronous Speed.(810 R.P.M.)
Constant Excitation.(34 Amps.)

E_c Volts	E' Volts	Power Kilo-Watts	Pos.of Brush Elec.Deg.
88.0	95.0	0.286	+90
87.5	95.0	0.286	80
87.0	95.0	0.286	70
87.3	95.0	0.286	60
88.3	95.0	0.291	50
88.3	95.0	0.311	40
91.3	95.0	0.326	30
91.3	95.0	0.331	20
91.0	96.5	0.331	10
90.4	96.5	0.321	0
91.3	96.5	0.311	-10
91.6	97.5	0.311	20
91.3	97.5	0.311	30
91.3	98.0	0.311	40
88.0	94.0	0.286	50
87.3	94.0	0.286	60
87.5	92.0	0.286	70
88.0	92.5	0.286	80
88.5	92.0	0.286	90

VARIATION OF TRANSFORMER VOLTAGE E",
GENERATOR VOLTAGE E_g (calculated),
and
E_c WITH THE POSITION OF THE BRUSHES

E_g Volts	E_c Volts	E" Volts	Pos.of Brush Elec.Deg.
0.0	88.0	89.0	+90
13.3	87.5	86.5	80
29.4	87.0	81.8	70
43.6	87.3	75.0	60
59.6	88.3	65.0	50
72.8	90.0	53.0	40
81.0	91.3	42.0	30
86.7	91.3	27.8	20
90.0	91.0	12.5	10
90.3	90.4	1.0	0
89.4	91.3	17.5	-10
85.8	91.6	32.0	20
78.5	91.3	46.5	30
66.6	90.0	60.5	40
54.5	88.0	69.0	50
46.1	87.3	74.0	60
33.0	87.5	81.0	70
24.5	88.0	84.5	80
20.4	88.5	86.6	90

VARIATION OF SPEED WITH VOLTAGE.
CONSTANT BRUSH POSITION.

15° Position

E' Volts	I Amperes	Power Kilo-Watts	Speed R. P. M.
0	0.0	0.000	0
30	13.0	0.105	100
35	15.4	0.143	170
40	16.8	0.218	310
45	19.5	0.280	360
50	22.5	0.356	394
55	25.3	0.431	400
60	28.5	0.518	404
65	31.8	0.656	450
70	35.5	0.843	560
75	37.8	1.093	730
80	41.0	1.263	740
85	47.0	1.543	746
90	52.5	1.713	740
95	59.5	2.043	730
100	67.0	2.293	710
110	85.5	3.043	710

Limited by sparking.

VARIATION OF SPEED WITH VOLTAGE.
CONSTANT BRUSH POSITION.

30° Position.

E' Volts	I Amperes	Power Kilo-Watts	Speed R. P. M.
0	0.0	0.000	0
20	7.0	0.080	62
25	11.3	0.180	228
30	14.5	0.230	234
35	17.6	0.318	220
40	21.3	0.438	214
45	26.3	0.458	218
50	30.0	0.543	222
55	35.0	0.681	238
60	40.0	0.867	268
65	47.5	1.163	314
70	52.5	1.406	344
75	59.5	1.796	424
80	64.5	2.336	546
85	56.5	3.586	1110
90	63.0	3.886	1100

Light Sparking.

VARIATION OF SPEED WITH VOLTAGE.
CONSTANT BRUSH POSITION.

45° Position.

E' Volts	I Amperes	Power Kilo-Watts	Speed R. P. M.
0	0.0	0.000	0
15	7.5	0.080	80
20	12.3	0.143	258
25	17.4	0.218	308
30	21.5	0.318	296
35	25.4	0.418	278
40	30.0	0.545	284
45	35.3	0.743	304
50	41.5	1.008	334
55	47.5	1.415	390
60	53.3	1.743	460
65	58.0	2.155	532
70	63.5	2.793	640
75	67.0	3.343	770
80	70.0	4.136	880

VARIATION OF SPEED WITH VOLTAGE.
CONSTANT BRUSH POSITION.

60° Position.

E′ Volts	I Amperes	Power Kilo-Watts	Speed R. P. M.
0	0.0	0.000	0
20	17.0	0.268	360
35	37.0	0.843	480
40	41.5	1.123	514
45	43.5	1.543	590
50	54.0	2.116	730
55	57.5	2.586	780
60	59.5	3.956	880
65	63.0	4.636	1020
70	65.5	3.986	1140

75° Position.

0	0.0	0.000	0
15	21.4	0.180	240
20	24.0	0.393	420
25	27.0	0.543	920
30	29.4	0.768	560
35	32.4	0.983	1360
40	32.0	1.143	1480
45	36.0	1.543	1550
50	38.0	1.793	1660
55	41.5	2.043	1860

VARIATION OF STATIC TORQUE WITH POSITION OF BRUSHES.
Constant Impressed E.M.F. (36.5 Volts)

Torque lb.in.	I Amperes	Power Kilo-Watts	Brush Pos. Elec.Deg.
41.4	79.0	1.586	+90
137.0	72.0	1.586	80
162.5	61.0	0.986	70
133.7	45.0	0.636	60
73.3	33.0	0.386	50
44.6	25.0	0.266	40
22.3	19.5	0.226	30
15.9	16.5	0.186	20
0.0	15.0	0.136	10
0.0	4.0	0.136	0
3.2	15.0	0.156	-10
12.7	17.6	0.186	20
44.6	21.8	0.236	30
60.6	28.2	0.286	40
72.0	34.0	0.386	45
117.7	38.7	0.486	50
156.0	52.5	0.786	60
153.0	68.5	1.286	70
76.5	80.0	1.686	80
Opposite Direction of Torque			90

VARIATION OF SPEED WITH POSITION OF BRUSHES.
CONSTANT IMPRESSED E. M. F.

40 Volts Impressed.

Field Amperes	Power Kilo-Watts	Speed R. P. M.	Pos.of Brush Elec.Degrees
		↷	
68.0	1.886	1200	+90
43.5	1.561	1580	85
35.2	1.286	1580	80
30.0	1.136	1520	75
27.5	1.036	1400	70
40.5	1.336	720	65
38.8	1.136	530	60
37.6	0.986	420	55
33.5	0.736	325	50
29.7	0.586	288	45
26.4	0.486	275	40
21.0	0.336	260	30
19.0	0.316	300	25
17.0	0.286	365	20
16.2	0.172	204	15
16.0	0.172	110	10
15.0	0.136	0	0
16.0	0.206	↶ 270	-10
18.5	0.286	360	20
23.0	0.336	220	30
29.5	0.536	240	40
34.0	0.716	302	45
37.6	0.886	360	50
41.4	1.136	455	55
25.4	------	----	60
28.0	1.086	1485	65
31.0	1.136	1600	70
35.4	1.336	1720	75
45.0	1.536	1680	80
61.0	1.836	1460	85
----	---REVERSED	----- ↷	90

EFFECT OF RESISTANCE AND INDUCTANCE IN THE ARMATURE CIRCUIT; UPON THE SPEED BRUSH-SHIFT CURVE.

Constant Impressed E.M.F.(40)

Brushes 1/8 in. Wide.

Normal Conditions.

Brush Pos. Elec.Deg.	I Amperes	Power Kilo-Watts	Speed R.P.M.
0	16.0	0.136	25 ↶
5	16.5	0.156	130
10	17.2	0.206	330
15	18.6	0.256	340
20	21.0	0.286	274
25	22.8	0.336	240
30	25.7	0.386	240
35	29.2	0.486	246
40	33.4	0.616	270
45	37.6	0.776	326
50	41.2	0.956	400
55	44.5	1.256	550
60	42.0	1.356	780
65	28.6	1.036	1580
70	30.0	1.136	1660
75	45.5	1.256	1710
80	47.0	1.486	1680
85	70.5	1.936	1330
90	80.0	1.936	1250 ↷

EFFECT OF RESISTANCE AND INDUCTANCE IN THE ARMATURE CIRCUIT, UPON THE SPEED-BRUSH-SHIFT CURVE.

Constant Impressed E.M.F.(40 Volts)

Brushes 1/8 in. Wide.

One Ohm Resistance in the Armature

Brush Pos. Elec.Deg.	I Amperes	Power Kilo-Watts	Speed R.P.M.
0	16.5	0.146	25
10	16.6	0.186	130
20	17.5	0.256	290
30	18.5	0.386	320
40	20.0	0.516	610
50	21.0	0.606	760
60	22.8	0.716	900
70	26.4	0.816	900
80	31.4	0.936	730
90	36.4	1.026	25

Inductance in Armature Circuit.

Brush Pos. Elec.Deg.	I Amperes	Power Kilo-Watts	Speed R.P.M.
0	17.0	0.136	25
5	16.4	0.156	120
10	17.2	0.160	230
15	17.4	0.206	400
20	18.0	0.250	570
25	18.5	0.306	650
30	19.6	0.350	700
40	21.6	0.450	830
50	23.6	0.586	1040
60	16.0	0.646	1230
70	28.8	0.626	1390
80	34.4	0.446	350
90	35.8	0.386	25

EFFECT OF RESISTANCE AND INDUCTANCE IN THE ARMATURE CIRCUIT,
UPON THE SPEED-BRUSH SHIFT CURVE.
Constant Impressed E.M.F.(40 Volts)
Brushes 1 inch Wide.

Normal Conditions.

Brush Pos. Elec.Deg.	I Amperes	Power Kilo-Watts	Speed R.P.M.
0	0.0	0.000	0
10	18.0	0.336	80
20	17.0	0.286	180
30	20.4	0.386	380
40	21.0	0.396	250
50	21.5	0.686	1020
60	22.0	0.730	1100
70	23.4	0.756	1266
80	27.0	0.936	1400
90	32.5	0.989	1416
90+10	46.5	1.386	1360
90+20	40.0	1.036	1330

EFFECT OF RESISTANCE AND INDUCTANCE IN THE ARMATURE CIRCUIT, UPON THE SPEED-BRUSH SHIFT CURVE.

Constant Impressed E.M.F.(40 Volts)

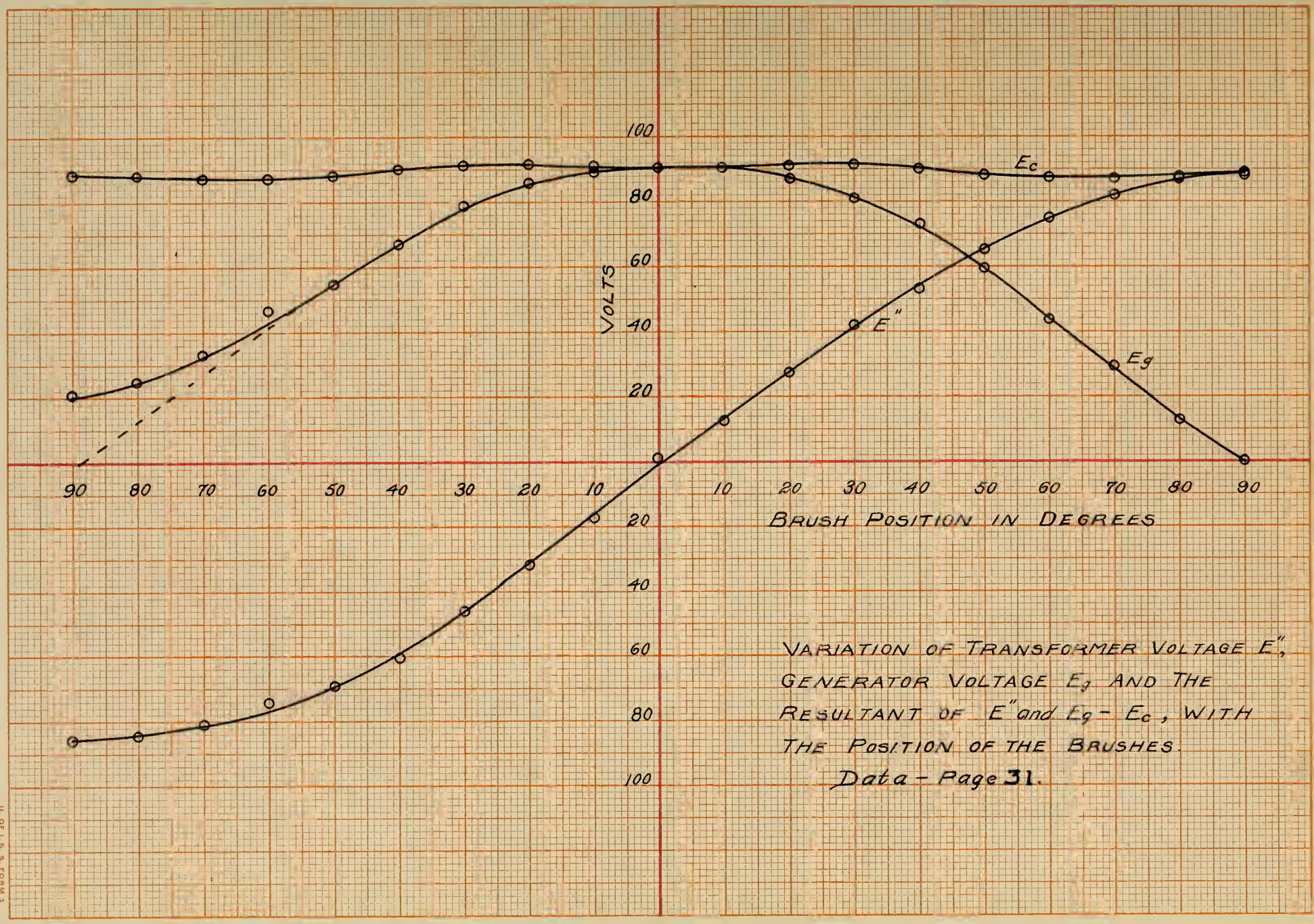
Brushes 1 inch Wide

Inductance in armature circuit.

Brush Pos. Elec.Deg.	I Amperes	Power Kilo-Watts	Speed R.P.M.
0	0.0	0.000	0
10	16.0	0.176	0
20	17.2	0.206	0
30	17.8	0.286	210
35	18.8	0.306	410
40	19.0	0.326	620
45	19.0	0.386	770
50	20.0	0.406	820
55	21.0	0.456	880
60	22.0	0.506	980
65	22.8	0.516	1020
70	24.2	0.556	1040
75	25.7	0.566	1080
80	26.5	0.566	1080
85	28.7	0.556	1050
90	30.0	0.536	830
90+10	---	----	Stopped

Resistance in armature circuit.

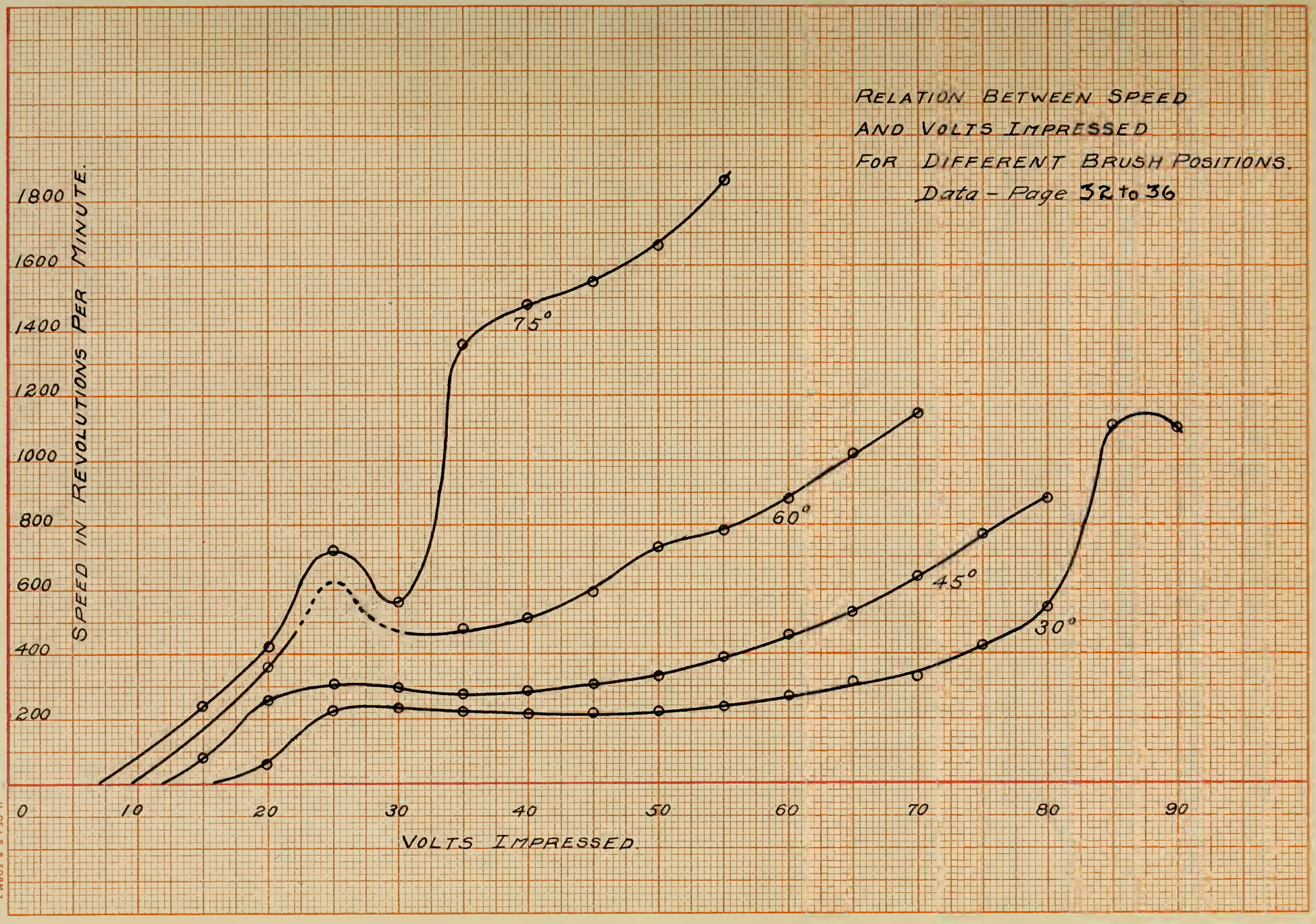
0	-----	------	---
10	-----	------	0
20	-----	------	0
30	18.0	0.336	149
40	19.0	0.406	320
50	19.5	0.456	480
60	21.0	0.586	610
70	22.5	0.656	720
80	25.0	0.816	850
90	27.0	0.876	640
90+10	-----	------	0

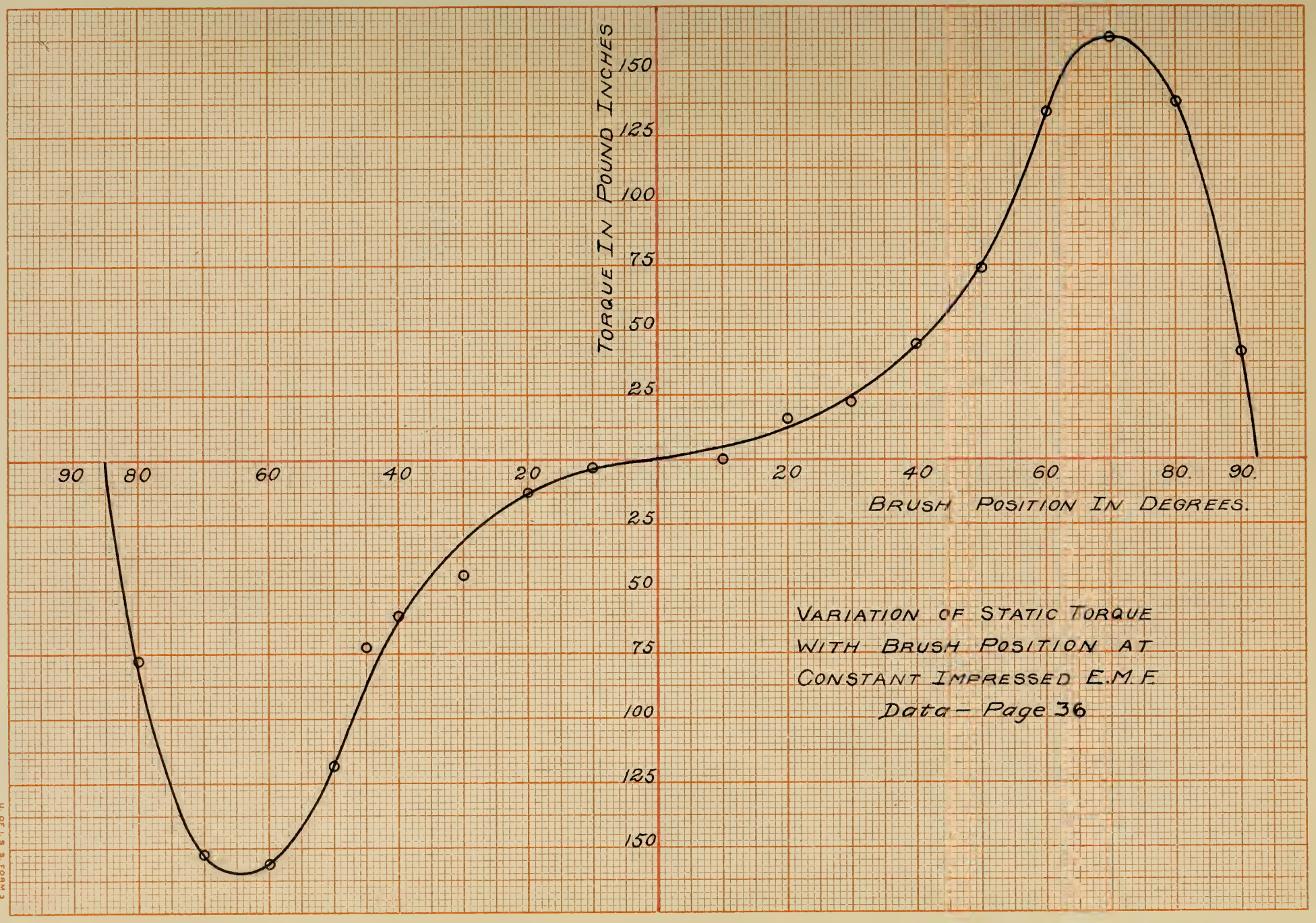


VARIATION OF TRANSFORMER VOLTAGE E", GENERATOR VOLTAGE E_g AND THE RESULTANT OF E" and $E_g - E_c$, WITH THE POSITION OF THE BRUSHES.

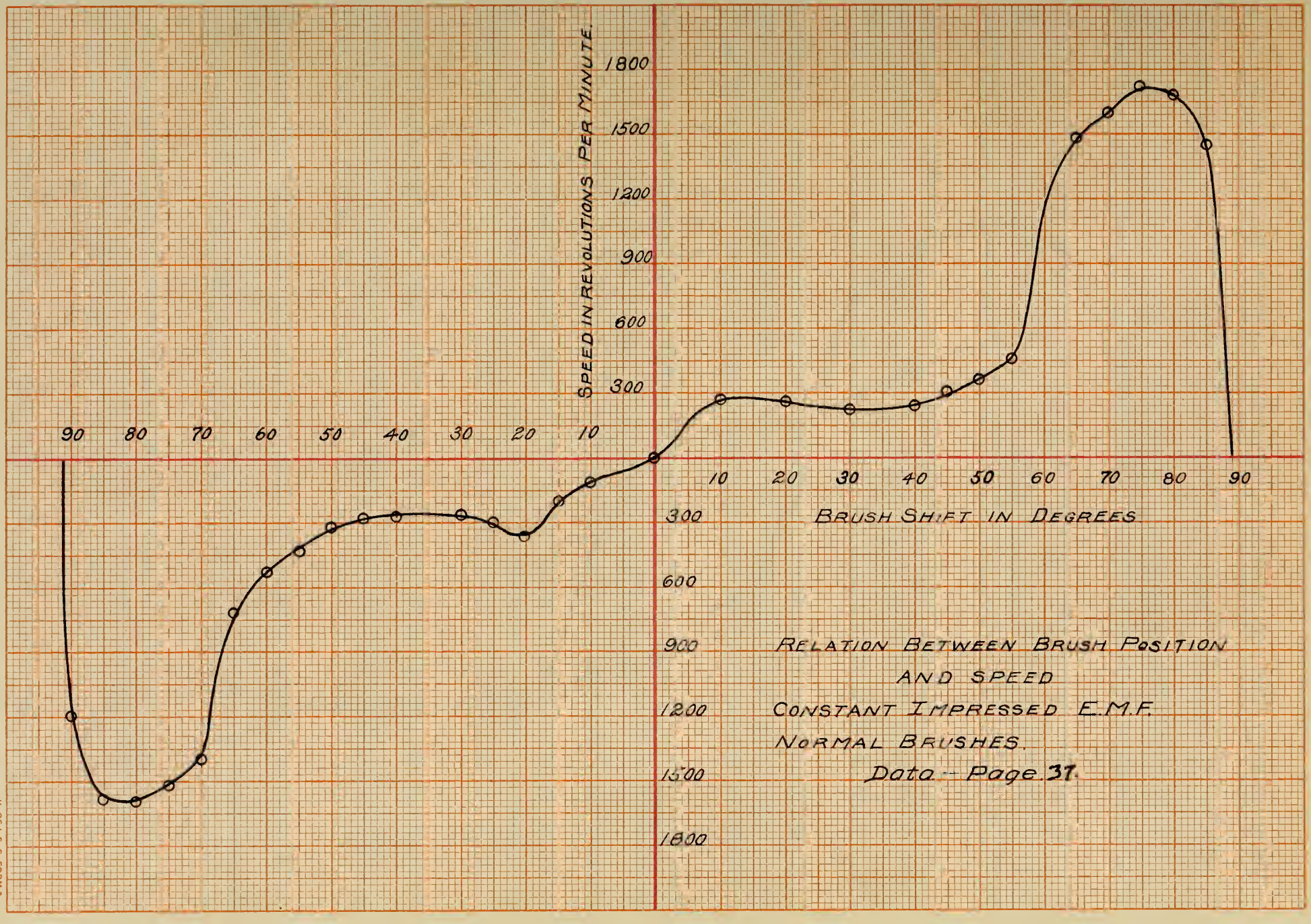
Data - Page 31.

U. OF I. S. FORM 3

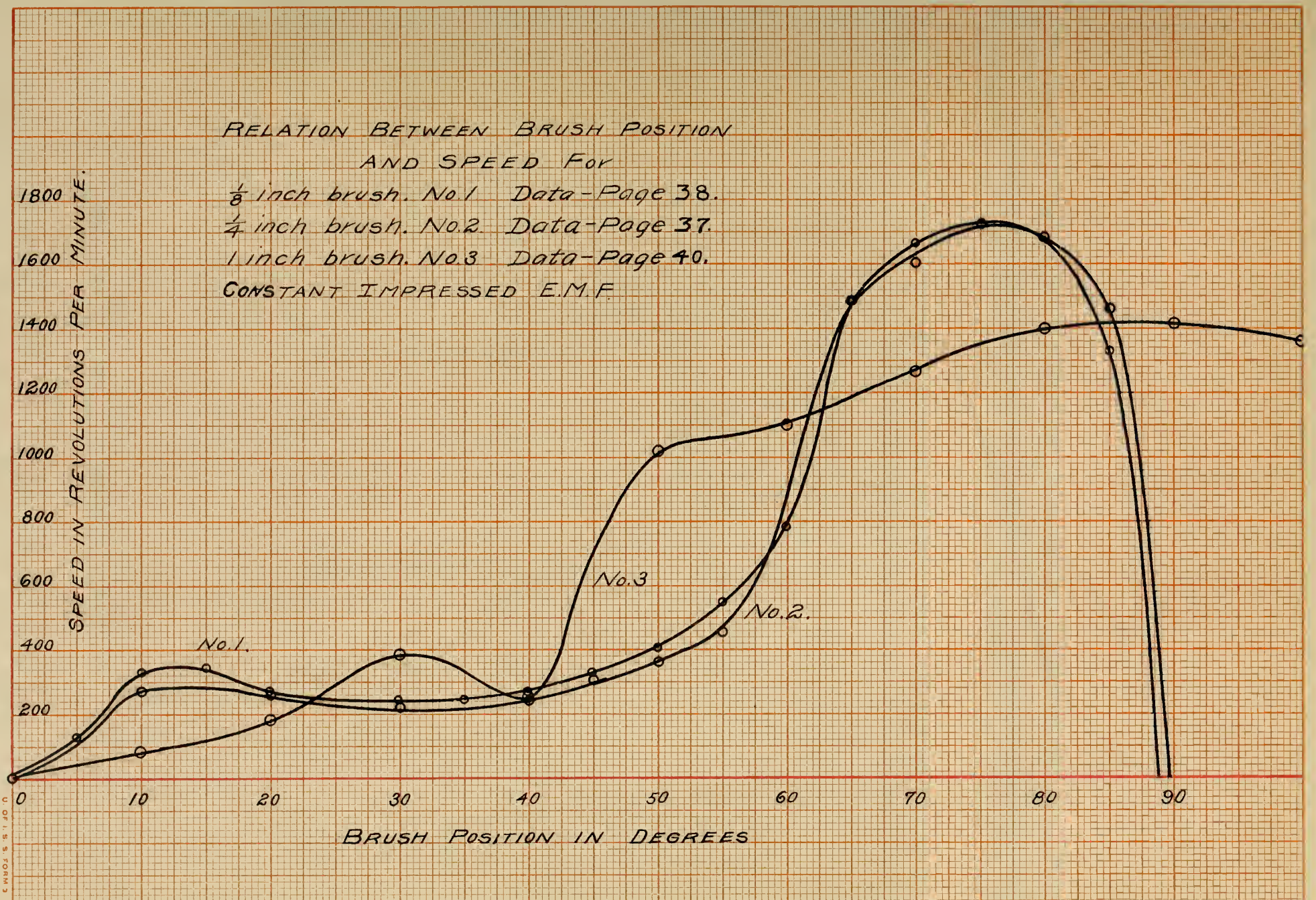

Relation Between Speed
And Volts Impressed
For Different Brush Positions.
Data - Page 32 to 36
Speed in Revolutions per Minute.
1800
1600
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
90
Volts Impressed.
75°
60°
45°
30°

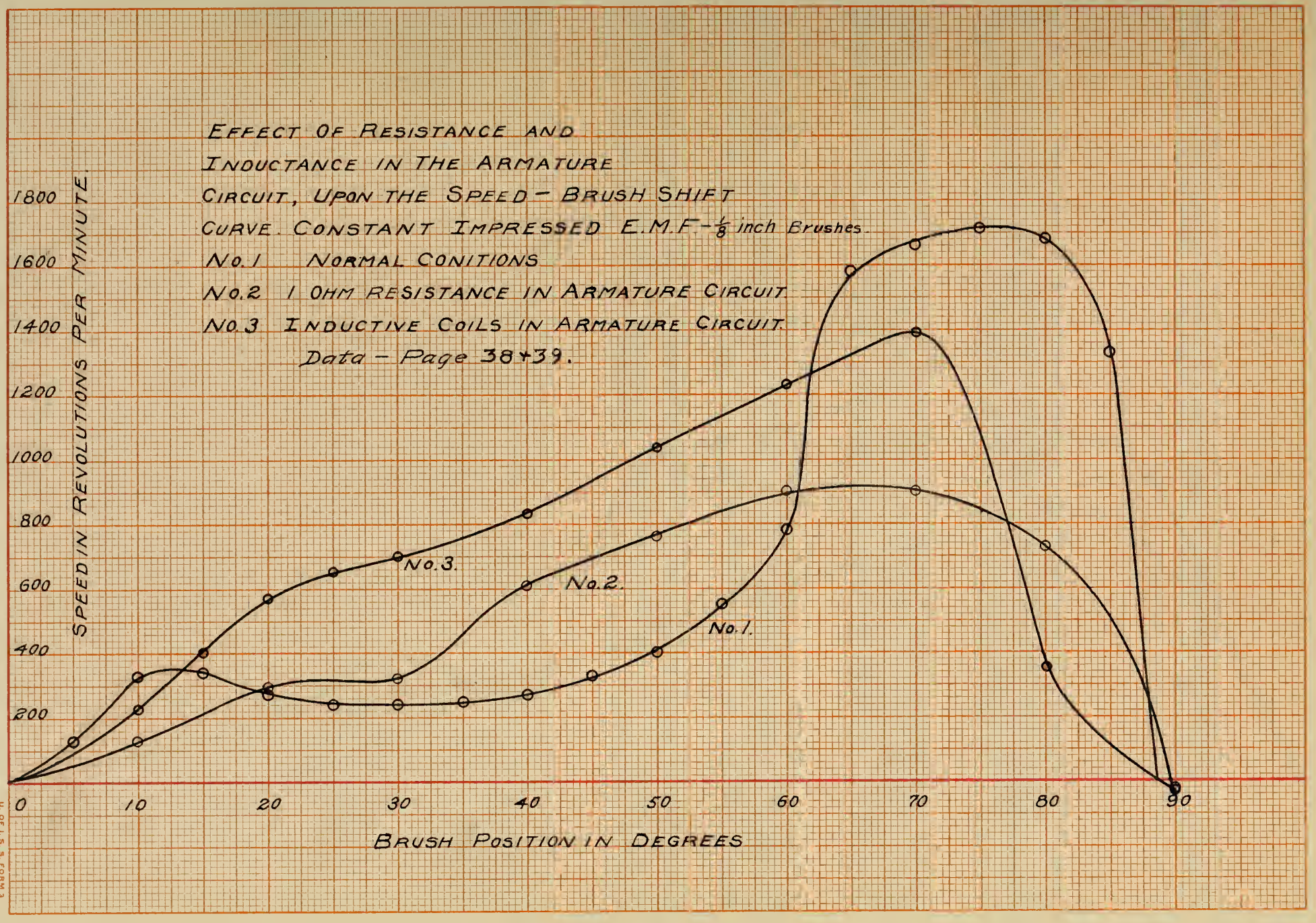


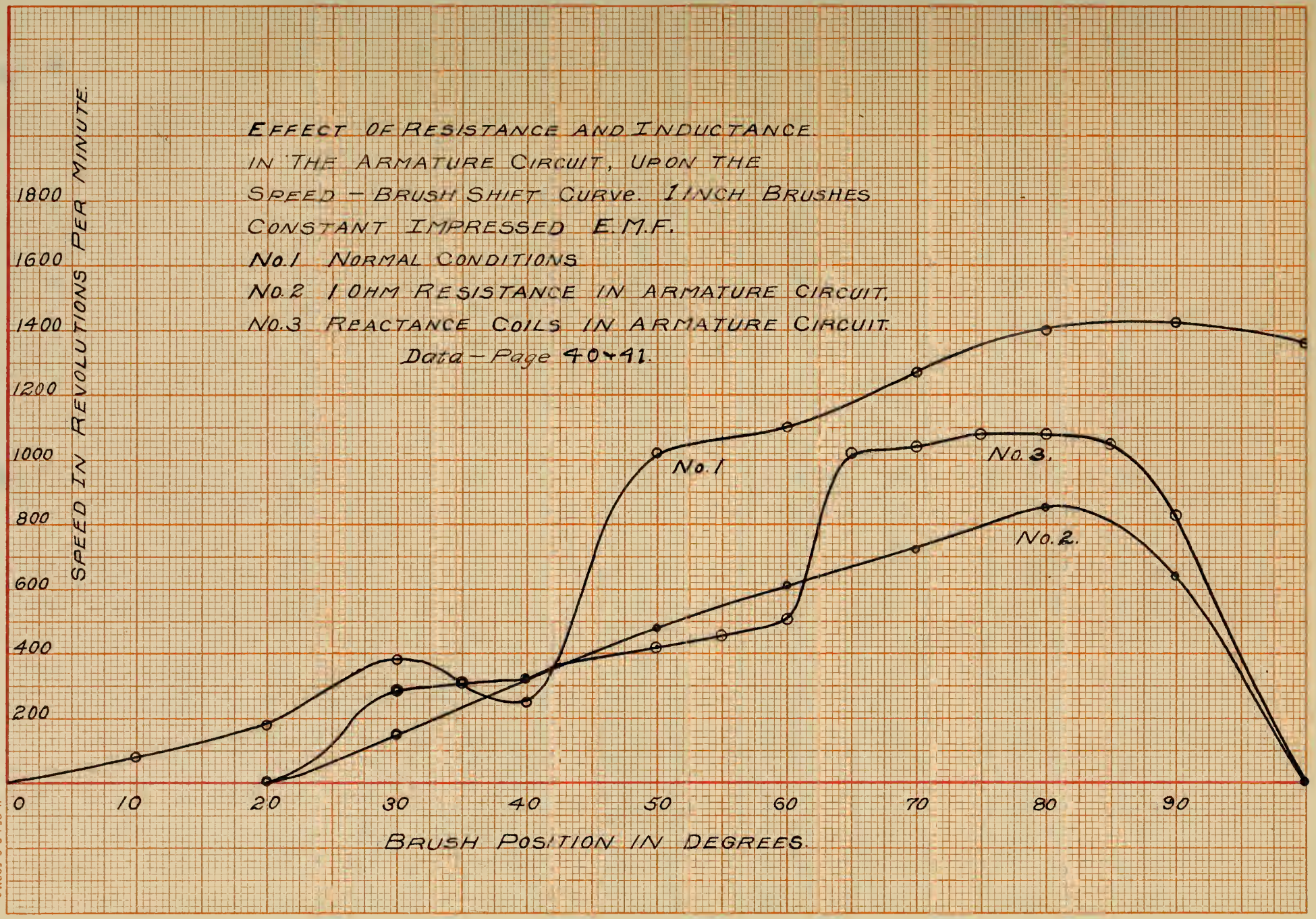
Variation of Static Torque
With Brush Position at
Constant Impressed E.M.F.
Data – Page 36


SPEED IN REVOLUTIONS PER MINUTE.
1800
1500
1200
900
600
300
90 80 70 60 50 40 30 20 10
10 20 30 40 50 60 70 80 90
300
600
900
1200
1500
1800
BRUSH SHIFT IN DEGREES
RELATION BETWEEN BRUSH POSITION
AND SPEED
CONSTANT IMPRESSED E.M.F.
NORMAL BRUSHES.
Data -- Page 37.

U. OF I. S. FORM 3


RELATION BETWEEN BRUSH POSITION
AND SPEED FOR
1/8 inch brush. No.1 Data-Page 38.
1/4 inch brush. No.2. Data-Page 37.
1 inch brush. No.3 Data-Page 40.
CONSTANT IMPRESSED E.M.F.
SPEED IN REVOLUTIONS PER MINUTE.
1800
1600
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
90
No.1.
No.2.
No.3
BRUSH POSITION IN DEGREES


Effect Of Resistance and
Inductance In The Armature
Circuit, Upon The Speed - Brush Shift
Curve. Constant Impressed E.M.F - ⅛ inch Brushes.
No. 1 Normal Conitions
No. 2 1 Ohm Resistance In Armature Circuit.
No. 3 Inductive Coils In Armature Circuit.
Data - Page 38+39.
Speed In Revolutions Per Minute.
1800
1600
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
90
No. 3.
No. 2.
No. 1.
Brush Position In Degrees


Effect of Resistance and Inductance
in the Armature Circuit, upon the
Speed – Brush Shift Curve. 1 Inch Brushes
Constant Impressed E.M.F.
No.1 Normal Conditions
No.2 1 Ohm Resistance in Armature Circuit.
No.3 Reactance Coils in Armature Circuit.
Data – Page 40-41.
Speed in Revolutions per Minute.
1800
1600
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
90
Brush Position in Degrees.
No.1
No.2.
No.3.

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